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Weak decay of hypernuclei – Theoretical status

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Abstract. The physics of the weak decay of hypernuclei is briefly reviewed from a theoretical point of view. Special regard is devoted to the recent progress concerning the determination of the non–mesonic decay widths and the asymmetry parameters. While convincing evidence has been achieved for a solution of the long–standing puzzle on the ratio Γ_n/Γ_p, the discrepancies between theory and experiment on the decay asymmetries clearly highlight the exigence of dedicating further efforts in exploring new aspects of the dynamics underlying the non–mesonic weak decay.

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1 Introduction

Hypernuclei can be considered as a powerful "laboratory" for unique investigations of baryon–baryon strangeness–changing weak interactions. The best studied systems are nuclei containing a Λ hyperon. In such nuclei the Λ can decay mesonically, by emitting a nucleon and a pion, $\Lambda \to \pi N$, as it occurs in free space; in addition, the hyperon (weak) interaction with the nucleons opens new decay channels, customarily indicated as non–mesonic modes. In particular, one can distinguish between one– and two–nucleon induced decays, $\Lambda N \to nN$ and $\Lambda NN \to nNN$, according whether the hyperon interacts with a single nucleon or with a pair of correlated nucleons.

The field of hypernuclear non–mesonic weak decay has recently experienced a phase of renewed interest, thanks to the ideation and accomplishment of innovative experiments as well as to the advent of elaborated theoretical models. For many years the main open problem in the decay of hypernuclei has been the discrepancy between theoretical and experimental values of the ratio Γ_n/Γ_p between the neutron– and proton–induced decay widths, $\Gamma_n \equiv \Gamma(\Lambda n \to nn)$ and $\Gamma_p \equiv \Gamma(\Lambda p \to np)$. This topic will be discussed in this contribution together with the most recent evidences for a solution of the puzzle.

Another interesting and open question we shall deal with concerns the asymmetric non–mesonic decay of polarized hypernuclei. Also in this case, as for the Γ_n/Γ_p puzzle, we expect important progress from the present and future improved experiments, which will provide a guidance for a deeper theoretical understanding of the hypernuclear decay mechanisms.

For comprehensive theoretical reviews on hypernuclear weak decay we refer the reader to Refs. [1,2] and references therein. The experimental viewpoint on the same subject has been discussed at this conference by H. Outa [3].

2 Weak decay modes of Λ hypernuclei – General properties

When a hypernucleus containing a single Λ hyperon is stable with respect to electromagnetic and strong processes, it is in the ground state, with the hyperon in the $1s$ level of the Λ–nucleus mean potential. From such a state the hypernucleus then decays via a strangeness–changing weak interaction, through the disappearance of the Λ.

The mesonic decay mode is the main decay channel of a Λ in free space, including the two channels $\Lambda \to \pi^- p$ and $\Lambda \to \pi^0 n$ with decay rates Γ_{π^-} and Γ_{π^0}, respectively. The experimental ratio for the free decay, $\Gamma^{\rm free}_{\pi^-}/\Gamma^{\rm free}_{\pi^0} \simeq 1.78$, is very close to 2 and thus strongly suggests the $\Delta I = 1/2$ rule on the isospin change. As it occurs in the decay of the Σ hyperon and in pionic kaon decays, this rule is based on experimental observations. Unfortunately, its dynamical origin is not yet convincingly understood on theoretical grounds.

The Q–value for the mesonic decay $Q_{\rm M} \simeq m_\Lambda - m_N - m_\pi \simeq 40$ MeV corresponds to a momentum of the final nucleon of about 100 MeV. As a consequence, in nuclei the Λ mesonic decay is disfavored by the Pauli principle, particularly in medium and heavy systems. It is strictly forbidden in normal infinite nuclear matter (where the Fermi momentum is $k^0_F \simeq 270$ MeV), while in finite nuclei it can occur because of three important effects:

1. In nuclei the hyperon has a momentum distribution that admits larger momenta for the final nucleon;
2. The final pion feels an attraction by the medium such that for fixed three–momentum $\boldsymbol{q}$ it has an energy smaller than the free one $[\omega(\boldsymbol{q}) < \sqrt{\boldsymbol{q}^{\,2} + m^2_\pi}]$, and consequently, due to energy conservation, the final nucleon again has more chance to come out above the Fermi surface;
3. At the nuclear surface the local Fermi momentum is

considerably smaller than k_F^0, and the Pauli blocking is less effective in forbidding the decay.

The mesonic channel can provide valuable information on the pion–nucleus optical potential since the decay widths Γ_{π^-} and Γ_{π^0} turn out to be very sensitive to the π^- and π^0 self–energies in the nuclear medium [4].

In hypernuclei the Λ decay also occurs through processes which involve a weak interaction of the hyperon with one or more nucleons. When the pion emitted by the weak vertex is virtual, it gets absorbed by the nuclear medium, resulting in non–mesonic processes of the following type:

$$\Lambda n \to nn \ (\Gamma_n)\,, \ \ \Lambda p \to np \ (\Gamma_p)\,, \ \ \Lambda NN \to nNN \ (\Gamma_2)\,.$$

More massive mesons than the pion can also mediate these decays [5,6]. Hybrid models adopting direct quark mechanisms in addition to meson–exchange potentials have also been proposed [7]. In these approaches, the baryon–baryon short range repulsion originates from quark–exchange between baryons.

The non–mesonic mode is only possible in nuclei and, nowadays, the systematic study of hypernuclear decay is the only practical way to get phenomenological information on the hyperon–nucleon weak interactions. This is especially facilitated by the fact that the final nucleons in the non–mesonic processes have large momenta ($p_N \simeq 420$ (340) MeV for the one–nucleon (two–nucleon) induced channel). Therefore, the non–mesonic mode is not blocked by the Pauli principle; on the contrary, it dominates over the mesonic mode for all but the s–shell hypernuclei. Being characterized by a large momentum transfer, the non–mesonic decay mode is only slightly affected by the details of hypernuclear structure, thus providing useful information directly on the hadronic weak interaction.

The total weak decay rate of a Λ hypernucleus is $\Gamma_{\rm T} = \Gamma_{\rm M} + \Gamma_{\rm NM}$, where $\Gamma_{\rm M} = \Gamma_{\pi^-} + \Gamma_{\pi^0}$, $\Gamma_{\rm NM} = \Gamma_1 + \Gamma_2$ and $\Gamma_1 = \Gamma_n + \Gamma_p$, while the lifetime is $\tau = \hbar/\Gamma_{\rm T}$. It is interesting to observe that there is an anticorrelation between mesonic and non–mesonic decay modes such that the total decay rate is quite stable from light to heavy hypernuclei. This behavior is evident from Figure 1 and is due to the rapid decrease of the mesonic width and to the saturation property of the $\Lambda N \to nN$ interaction for increasing nuclear mass number.

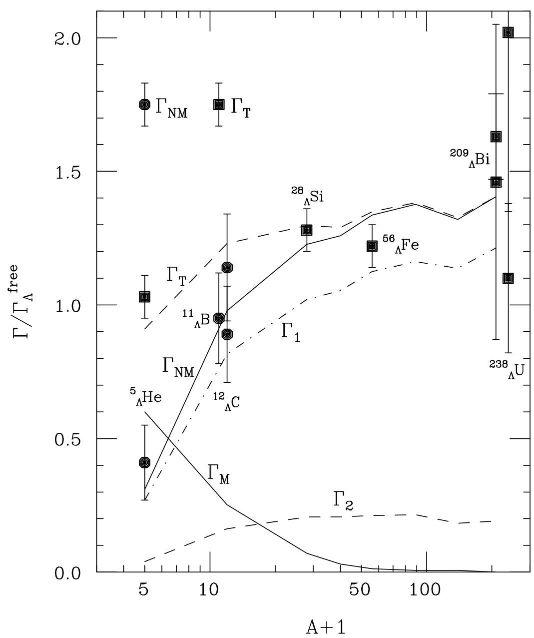

Fig. 1. Decay widths of the Λ in finite nuclei as a function of the nuclear mass number A (taken from Refs. [1,8]).

3 The ratio Γ_n/Γ_p

Up to very recent times, the main challenge of hypernuclear weak decay studies has been to provide a theoretical explanation of the large experimental values for the ratio Γ_n/Γ_p [1,2]. During this period, large uncertainties involved in the extraction of this ratio from data did not allow to reach any definitive conclusion. These “old ”data [9,10,11] were quite scarce and not precise due to the difficulty of detecting the products of the non–mesonic decays, especially the neutrons. Moreover, up to now it has not been possible to distinguish between nucleons produced by the one–body induced and the (non–negligible) two–body induced decay mechanisms. These limitations lead to very indirect experimental determinations of the decay rates Γ_n and Γ_p from single–nucleon spectra measurements. Particularly in the last few years, this persistent, puzzling status has encouraged a renewed interest for hypernuclear non–mesonic decay. Thanks to recent theoretical [7,12,13,14,15,16,17,18,19] and experimental [3,20,21,22,23,24] progress, we can now safely affirm that the Γ_n/Γ_p puzzle has been solved. A decisive role in this achievement has been played by the first measurements of nucleon–coincidence spectra together with a non–trivial interpretation of data, which required theoretical analyses of two–nucleon induced decays and accurate studies of nuclear medium effects on the weak decay nucleons. We summarize these important developments in the following.

One–pion–exchange (OPE) models predict small ratios, typically around 0.1-0.2 for the most studied systems, $^5_\Lambda$He and $^{12}_\Lambda$C. This is mainly due to the particular form of the OPE potential, which has a strong tensor component, $\Lambda N(^3S_1) \to nN(^3D_1)$, requiring isospin 0 np pairs in the antisymmetric final state. On the contrary, the OPE model has been able to reproduce the total non–mesonic rates measured for the above mentioned hypernuclei [1,2].

Other interaction mechanisms beyond the OPE might then be responsible for the overestimation of Γ_p and the underestimation of Γ_n. Many attempts have been made in order to solve the Γ_n/Γ_p puzzle. We recall here the inclusion in the $\Lambda N \to nN$ transition potential of mesons heavier than the pion [5,6,12,13,14], the implementation of interaction terms that explicitly violate the $\Delta I = 1/2$ rule [25,26] and the description of the short range baryon–baryon interaction in terms of quark degrees of freedom

[7], which automatically introduces $\Delta I = 3/2$ contributions.

A few investigations with transition potentials including heavy–meson–exchange and/or direct quark (DQ) contributions have recently improved the situation, without providing an explanation of the origin of the puzzle. As discussed in the next paragraphs, the proper determination of Γ_n/Γ_p from data indeed required an analysis of the two–nucleon induced decay mechanism and an accurate evaluation of the final state interactions suffered by the detected nucleons. In Tables 1 and 2 we summarize the results of those calculations which predicted ratios considerably enhanced with respect to the OPE values together with experimental data. The variety of models adopted in the quoted works has been extensively discussed in Ref. [1]. Here we only mention that, with respect to the OPE results, the addition of kaon–exchange is found to considerably reduce $\Gamma_{\rm NM}$ while increasing Γ_n/Γ_p by a factor of about 4. This result is mainly due to i) the enhancement of the parity–violating $\Lambda N(^3S_1) \to nN(^3P_1)$ transition contributing especially to neutron–induced decays and ii) the tensor component of kaon–exchange, which has opposite sign with respect to the OPE one, thus increasing Γ_n and reducing Γ_p. Also the DQ mechanism revealed to be important to obtain larger Γ_n/Γ_p. All the approaches of Tables 1 and 2 but the one of Ref. [18] reproduce the observed non–mesonic widths. We note that the use of a more realistic Λ wave function would lead to a reduction of about 25% [19] of the non–mesonic rate evaluated in Ref. [18]. Although no calculation of Table 1 is able to explain the data of Refs. [9,10,11,27], extracted from single–nucleon measurements, some predictions are in agreement with the recent determinations of Refs. [16,19] obtained by fitting the nucleon–nucleon coincidence data of Refs. [3,22, 23,24]. In the remainder of the present Section we discuss these recent achievements, which made possible a solution of the Γ_n/Γ_p puzzle.

The authors of Refs. [15,16] evaluated neutron–neutron and neutron–proton energy and angular correlations for $^5_\Lambda$He and $^{12}_\Lambda$C and analyzed the corresponding data obtained by the experiments KEK–E462 and KEK–E508. A one–meson–exchange (OME) model was used for the $\Lambda N \to nN$ transition in a finite nucleus framework. The two–nucleon induced decay channel $\Lambda np \to nnp$ was taken into account via the polarization propagator method in the local density approximation [8], a model applied for the first time to hypernuclear decay in Ref. [28]. The intranuclear cascade code of Ref. [29] was employed to simulate the nucleon propagation inside the residual nucleus. In Table 3 the ratios N_{nn}/N_{np} predicted by the OPE model and two OME models (OMEa and OMEf, using NSC97a and NSC97f potentials, respectively) of Refs. [15,16] are given for the back–to–back kinematics ($\cos\theta_{NN} \le -0.8$) and nucleon kinetic energies $T_n, T_p \ge 30$ MeV. The predictions for Γ_n/Γ_p are also quoted. The OME results well reproduce the data, thus indicating a ratio $\Gamma_n/\Gamma_p \simeq 0.3$ for both hypernuclei, in agreement with some of the pure theoretical determinations of Table 1.

Table 3. Predictions of Refs. [15,16] for the ratio N_{nn}/N_{np} corresponding to an energy thresholds $T_N^{\rm th}$ of 30 MeV and to the back–to–back kinematics ($\cos\theta_{NN} \le -0.8$). The data are from KEK–E462 and KEK–E508 [3,22,23,24].

	$^5_\Lambda$He		$^{12}_\Lambda$C	
	N_{nn}/N_{np}	Γ_n/Γ_p	N_{nn}/N_{np}	Γ_n/Γ_p
OPE	0.25	0.09	0.24	0.08
OMEa	0.51	0.34	0.39	0.29
OMEf	0.61	0.46	0.43	0.34
EXP	0.45 ± 0.11		0.40 ± 0.10	

A weak–decay–model independent analysis of the coincidence data of Table 3 has been performed in Ref. [15]. The results are given in Table 1 either by neglecting the two–nucleon stimulated decay channel ($1N$) or by adopting $\Gamma_2/\Gamma_1 = 0.20$ for $^5_\Lambda$He and $\Gamma_2/\Gamma_1 = 0.25$ for $^{12}_\Lambda$C ($1N + 2N$), as predicted in Ref. [8]. The Γ_n/Γ_p values determined in this way are in agreement with the pure theoretical predictions of Refs. [12,13,14,17,18] (see Table 1) but are substantially smaller than those obtained experimentally from single–nucleon spectra analyses [9,10, 11,27]. In our opinion, this result represents a strong evidence for a solution of the long–standing puzzle on the Γ_n/Γ_p ratio.

This conclusion has been corroborated by a recent study [19], analogous to the one of Ref. [16] but performed within a nuclear matter formalism adapted to finite nuclei via the local density approximation (see the results in Table 1). At variance with Ref. [16], a microscopic model more in line with the functional approach of Ref. [30] has been followed for the two–nucleon induced decays, also including the channels $\Lambda nn \to nnn$ and $\Lambda pp \to npp$ besides the standard mode $\Lambda np \to nnp$ of the previous phenomenological approach.

Forthcoming coincidence data from KEK, BNL [31], J–PARC [32] and FINUDA [33] could be directly compared with the results of Refs. [15,16,19]. This will permit to achieve better determinations of Γ_n/Γ_p and to establish the first constraints on Γ_2/Γ_1.

4 The asymmetry puzzle

Despite the recent progress just discussed, the reaction mechanism for the non–mesonic decay does not seem to be fully understood. Indeed, a new intriguing problem, of more recent origin, is open: it concerns a strong disagreement between theory and experiment on the asymmetry of the angular emission of non–mesonic decay protons from polarized hypernuclei. This asymmetry is due to the interference between parity–violating and parity–conserving $\Lambda p \to np$ transition amplitudes [34], while the widely considered rates Γ_n and Γ_p are dominated by the parity–conserving part of the interaction. The study of the asymmetric emission of protons from polarized hypernuclei is thus supposed to provide new constraints on the dynamics of hypernuclear decay.

Table 1. Theoretical and experimental determinations of the Γ_n/Γ_p ratio.

Ref. and Model	${}^{5}_{\Lambda}$He	${}^{12}_{\Lambda}$C
Sasaki et al. [7]	0.70	
$\pi + K +$ DQ		
Jido et al. [12]		0.53
$\pi + K + 2\pi/\sigma + 2\pi + \omega$		
Parreño and Ramos [13]	$0.34 \div 0.46$	$0.29 \div 0.34$
$\pi + \rho + K + K^* + \omega + \eta$		
Itonaga et al. [14]	0.39	0.37
$\pi + 2\pi/\sigma + 2\pi/\rho + \omega$		
Barbero et al. [17]	0.24	0.21
$\pi + \rho + K + K^* + \omega + \eta$		
Bauer and Krmpotić [18]		0.29
$\pi + \rho + K + K^* + \omega + \eta$		
BNL [9]	0.93 ± 0.55	$1.33^{+1.12}_{-0.81}$
KEK [10]		$1.87^{+0.67}_{-1.16}$
KEK [11]	1.97 ± 0.67	
KEK–E307 [27]		0.87 ± 0.23
KEK–E462 [23]	$0.45 \pm 0.11 \pm 0.03$	
KEK–E508 [24]		$0.51 \pm 0.13 \pm 0.05$
KEK–E462/E508 (analysis of Ref. [16])	0.40 ± 0.11 ($1N$)	0.38 ± 0.14 ($1N$)
	0.27 ± 0.11 ($1N + 2N$)	0.29 ± 0.14 ($1N + 2N$)
KEK–E462/E508 (analysis of Ref. [19])		0.37 ± 0.14 ($1N$)
		0.34 ± 0.15 ($1N + 2N$)

Table 2. Theoretical and experimental determinations of the non–mesonic width Γ_{NM} (in units of $\Gamma_\Lambda^{\rm free}$). Only the one–nucleon induced decay channel has been taken into account in the theoretical evaluations.

Ref. and Model	${}^{5}_{\Lambda}$He	${}^{12}_{\Lambda}$C
Sasaki et al. [7]	0.52	
$\pi + K +$ DQ		
Jido et al. [12]		0.77
$\pi + K + 2\pi/\sigma + 2\pi + \omega$		
Parreño and Ramos [13]	$0.32 \div 0.43$	$0.55 \div 0.73$
$\pi + \rho + K + K^* + \omega + \eta$		
Itonaga et al. [14]	0.42	1.06
$\pi + 2\pi/\sigma + 2\pi/\rho + \omega$		
Barbero et al. [17]	0.69	1.17
$\pi + \rho + K + K^* + \omega + \eta$		
Bauer and Krmpotić [18]		1.64
$\pi + \rho + K + K^* + \omega + \eta$		
BNL [9]	0.41 ± 0.14	1.14 ± 0.20
KEK [10]		0.89 ± 0.18
KEK [11]	0.50 ± 0.07	
KEK–E307 [27]		$0.828 \pm 0.056 \pm 0.066$
KEK–E462 [22]	0.424 ± 0.024	
KEK–E508 [22]		0.940 ± 0.035
KEK–E462 [3]	$0.411 \pm 0.023 \pm 0.006$	
KEK–E508 [3]		$0.929 \pm 0.027 \pm 0.016$

The intensity of protons emitted in $\Lambda p \to np$ decays along a direction forming an angle Θ with the polarization axis is given by (see Ref. [35] for more details):

$$I(\Theta, J) = I_0(J)\,[1 + \mathcal{A}(\Theta, J)]\,, \qquad (1)$$

I_0 being the (isotropic) intensity for an unpolarized hypernucleus. In the shell model weak–coupling scheme, the proton asymmetry parameter takes the following form:

$$\mathcal{A}(\Theta, J) = p_\Lambda(J)\, a_\Lambda \cos\Theta, \qquad (2)$$

p_Λ being the polarization of the Λ spin and a_Λ the *intrinsic* Λ asymmetry parameter, which is expected to be a characteristic of the elementary process $\Lambda p \to np$.

Nucleon final state interactions (FSI) acting after the non–mesonic process modify the weak decay intensity (1).

Experimentally, one has access to a proton intensity $I^{\rm M}$ which is assumed to have the same Θ–dependence as I:

$$I^{\rm M}(\Theta, J) = I^{\rm M}_0(J)\left[1 + p_\Lambda(J)\, a^{\rm M}_\Lambda(J)\cos\Theta\right] . \qquad (3)$$

The *observable* asymmetry, $a^{\rm M}_\Lambda(J)$, which is expected to depend on the hypernucleus, is then determined as:

$$a^{\rm M}_\Lambda(J) = \frac{1}{p_\Lambda(J)}\frac{I^{\rm M}(0^\circ, J) - I^{\rm M}(180^\circ, J)}{I^{\rm M}(0^\circ, J) + I^{\rm M}(180^\circ, J)} . \qquad (4)$$

While inexplicable inconsistencies appeared between the first asymmetry experiments of Refs. [36,37], as discussed in Ref. [1], very recent and more accurate data [3, 22,38,39] favor small $a^{\rm M}_\Lambda$ values, compatible with a vanishing value, for both s– and p–shell hypernuclei. On the contrary, theoretical models based on OME potentials and/or DQ mechanisms predicted rather large and negative a_Λ values (see Table 4). It must be noted that, on the contrary, the mentioned models have been able to account fairly well for the other weak decay observables (Γ_{NM} and Γ_n/Γ_p) measured for s– and p–shell hypernuclei.

Concerning the above comparison between theory and experiment, it is important to stress that, while one predicts $a_\Lambda(^5_\Lambda{\rm He}) \simeq a_\Lambda(^{12}_\Lambda{\rm C})$, there is no known reason to expect this approximate equality to be valid for $a^{\rm M}_\Lambda$. Indeed, the relationship between $I(\Theta, J)$ of Eq. (1) and $I^{\rm M}(\Theta, J)$ of Eq. (3) can be strongly affected by FSI of the emitted protons, thus preventing a direct comparison between a_Λ and $a^{\rm M}_\Lambda$. To overcome this obstacle, an evaluation of the FSI effects on the non–mesonic decay of polarized hypernuclei has been recently performed [42] adopting the same framework of Refs. [15,16].

We summarize here some results of this investigation, which is the first one evaluating $a^{\rm M}_\Lambda$. The simulated proton intensities turned out to be well fitted by Eq. (3); one can thus evaluate $a^{\rm M}_\Lambda$ through Eq. (4). Table 5 shows OME predictions for the intrinsic and observable asymmetries. As a result of the nucleon rescattering in the nucleus, $|a_\Lambda| \gtrsim |a^{\rm M}_\Lambda|$ for any value of the proton kinetic energy threshold: when $T^{\rm th}_p = 0$, $a_\Lambda/a^{\rm M}_\Lambda \simeq 2$ for $^5_\Lambda$He and $a_\Lambda/a^{\rm M}_\Lambda \simeq 4$ for $^{12}_\Lambda$C; $|a^{\rm M}_\Lambda|$ increases with $T^{\rm th}_p$ and $a_\Lambda/a^{\rm M}_\Lambda \simeq 1$ for $T^{\rm th}_p = 70$ MeV in both cases. Values of $a^{\rm M}_\Lambda$ rather independent of the hypernucleus are obtained for $T^{\rm th}_p = 30$, 50 and 70 MeV. The data quoted in the table refer to a $T^{\rm th}_p$ of about 30 MeV; the corresponding predictions of Ref. [42] barely agree with the $^{12}_\Lambda$C datum but are inconsistent with the observation for $^5_\Lambda$He.

Recently, an effective field theory approach based on tree–level pion– and kaon–exchange and leading–order contact interactions has been applied to hypernuclear decay [43]. The coefficients of the considered four–fermion point interaction have been fitted to reproduce available data for the non–mesonic decay widths of $^5_\Lambda$He, $^{11}_\Lambda$B and $^{12}_\Lambda$C. In this way, a dominating central, spin–and isospin–independent contact term has been predicted. Such term turned out to be particularly important to reproduce a small and positive value of the intrinsic asymmetry for $^5_\Lambda$He, as indicated by the recent KEK experiments. In order to improve the comparison with the observed decay asymmetries in a calculation scheme based on a meson–exchange model, this result can be interpreted dynamically as the need for the introduction of a scalar–isoscalar meson–exchange.

Table 5. Results of Ref. [42] for the asymmetries a_Λ and $a^{\rm M}_\Lambda$.

FSI, $T^{\rm th}_p$(MeV)	$^5_\Lambda$He	$^{12}_\Lambda$C
no FSI, 0	$a_\Lambda = -0.68$	$a_\Lambda = -0.73$
with FSI, 0	-0.30	-0.16
with FSI, 30	-0.46	-0.37
with FSI, 50	-0.52	-0.51
with FSI, 70	-0.55	-0.65
KEK–E462 [38]	$0.11 \pm 0.08 \pm 0.04$	
KEK–E462 [39]	$0.07 \pm 0.08^{+0.08}_{-0.00}$	
KEK–E508 [38]		$-0.20 \pm 0.26 \pm 0.04$
KEK–E508 [39]		$-0.16 \pm 0.28^{+0.18}_{-0.00}$

Prompted by the work of Ref. [43], models based on OME and/or DQ mechanisms [44,45] have been supplemented with the exchange of the scalar–isoscalar σ–meson. Despite the rather phenomenological character of these works (the unknown σ weak couplings are fixed to fit non–mesonic decay data for $^5_\Lambda$He), they have clearly demonstrated the importance of σ–exchange in the non–mesonic decay. More detailed investigations are needed to establish the precise contribution of the scalar–isoscalar channel.

4.1 Conclusions

Experimental and theoretical studies of nucleon coincidence spectra have recently lead to a solution of the long–standing puzzle on the ratio Γ_n/Γ_p. Nowadays, values of Γ_n/Γ_p around 0.3-0.4 are common to both theoretical and experimental analyses of s– and p–shell hypernuclei. An important role in this achievement has been played by a non–trivial interpretation of data, which required analyses of two–nucleon induced decays and accurate studies of nuclear medium effects on the weak decay nucleons.

Despite this improvement, the reaction mechanism for the hypernuclear non–mesonic weak decay does not seem to be understood in detail. Indeed, an intriguing problem remains open. It regards an asymmetry of the angular emission of non–mesonic weak decay protons from polarized hypernuclei. Although nucleon FSI turned out to be an important ingredient also when dealing with this issue, further investigations are required to solve the problem.

On the theoretical side, recent indications on the relevance of the scalar–isoscalar channel seem to suggest novel reaction mechanisms to improve our knowledge of the dynamics underlying the non–mesonic decay. New and improved experiments more clearly establishing the sign and magnitude of $a^{\rm M}_\Lambda$ for s– and p–shell hypernuclei are also necessary. Future experimental studies of the inverse reaction $pn \to p\Lambda$ using polarized proton beams should also be encouraged: this process could give a rich and clean piece of information on the Λ–nucleon weak interaction and especially on the Λ polarization observables [46].

Table 4. Theoretical and experimental determinations of the asymmetry parameters (a_Λ and a_Λ^{M}, respectively).

Ref. and Model	${}^{5}_{\Lambda}$He	${}^{12}_{\Lambda}$C
Sasaki et al. [7]		
$\pi + K + \mathrm{DQ}$	-0.68	
Parreño and Ramos [13]		
$\pi + \rho + K + K^* + \omega + \eta$	-0.68	-0.73
Itonaga et al. [40]		
$\pi + K + 2\pi/\sigma + 2\pi/\rho + \omega$	-0.33	
Barbero et al. [41]		
$\pi + \rho + K + K^* + \omega + \eta$	-0.54	-0.53
KEK–E160 [36]		-0.9 ± 0.3
KEK–E278 [37]	0.24 ± 0.22	
KEK–E462 [38]	$0.11 \pm 0.08 \pm 0.04$	
KEK–E462 [39]	$0.07 \pm 0.08^{+0.08}_{-0.00}$	
KEK–E508 [38]		$-0.20 \pm 0.26 \pm 0.04$
KEK–E508 [39]		$-0.16 \pm 0.28^{+0.18}_{-0.00}$

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